Nuclear Renaissance

Reevaluating Nuclear Power's Future

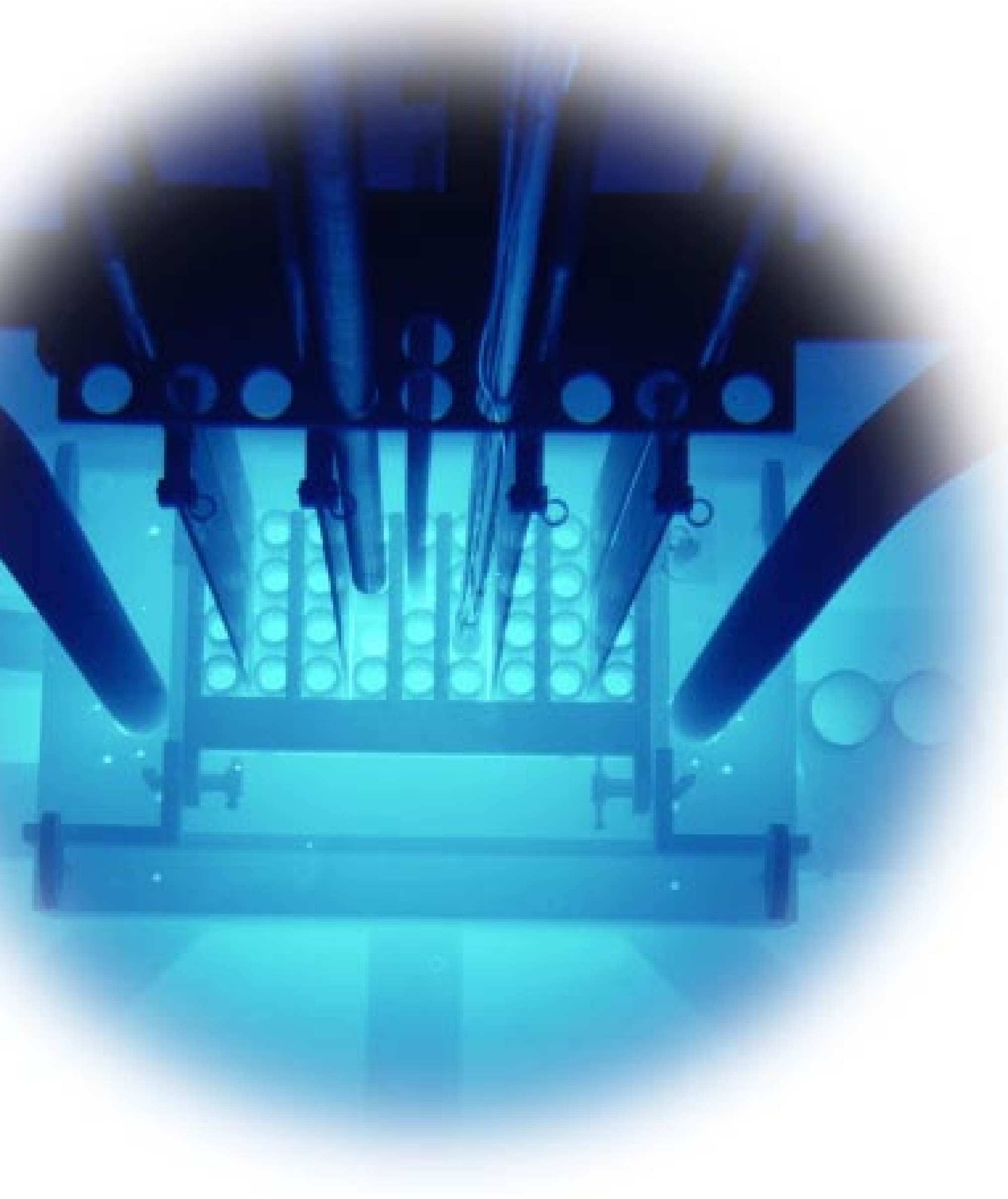
by Brian Fishbine

Growing levels of atmospheric carbon dioxide are raising concerns of global warming and sparking renewed interest in nuclear power. Unlike coal- and gas-fired power plants, nuclear power plants provide electricity without emitting carbon dioxide. They could also enable a hydrogen economy.

The core of the Omega West Reactor, which was used at Los Alamos from 1956 until 1992 for a variety of research projects. The reactor's fuel rods were immersed in water, which provided cooling, moderation, and radiation shielding. The blue glow—called Cherenkov radiation—is light emitted by electrons from the reactor that travel faster than the speed of light in water.

Eighty-five percent of the 14 million megawatts of power consumed worldwide comes from burning fossil fuels, a process that annually pours 27 billion tons of carbon dioxide, a major greenhouse gas, into the atmosphere. We can minimize carbon dioxide emissions by producing and using energy more efficiently; by sequestering carbon dioxide; by expanding the use of renewable energy sources, such as solar energy, wind power, and hydroelectric power; and by expanding the use of nuclear power, which is the only large-scale source of electricity other than hydroelectric power that does not generate greenhouse gases.

In fact, nuclear power plants already provide 20 percent of the electricity consumed in the United States. There are currently 104 nuclear power plants



in 31 states (see the map on page 24). However, the Department of Energy forecasts that by 2020, the United States will almost double its electrical power consumption to more than 800,000 megawatts. To supply that power will require 1,300 to 1,900 new power plants, many of which could be nuclear.

But to expand the use of nuclear power, we must ensure that existing nuclear power plants continue to operate safely beyond their original design lifetime of 40 years, simplify reactor regulations without compromising reactor safety, and build new nuclear power plants that are simpler, cheaper, safer, and less prone to terrorist attack. In addition, we must dispose of spent nuclear fuel both safely and securely and prevent the diversion of weapons-grade nuclear material from existing power plants. Several Los Alamos programs address these issues.

Reactor Safety, Security, and Economics

Los Alamos scientists first began to work with reactor fuel—specifically, uranium and plutonium—during the Manhattan Project because these elements also fuel nuclear weapons. Since then, Los Alamos studies of uranium and plutonium have contributed to both weapon and reactor science.

One of the more recent reactor-related programs at Los Alamos has improved the safety of existing power reactors. In 1998, at the request of the U.S. Nuclear Regulatory Commission (NRC), Los Alamos scientists began studying a problem with the emergency core-cooling systems of nuclear power plants.

Normally, a nuclear reactor's core is cooled in a bath of water under high pressure; the core and bath are contained in a large vessel. A break or leak in the pipes that circulate water to and from the vessel or in the vessel itself could lead to excessive core heating. The emergency system cools the core if the regular cooling system fails.

The principal investigator for the cooling-system work done at Los Alamos was D. V. Rao, now deputy director of Decision Applications Division. Using computer simulations, small-scale experiments, and prototype tests, the Los Alamos scientists determined the severity of the problem and ways to fix it. They also helped the NRC develop regulations to address the problem and inspected power plants where corrections had been made. So far, thirty-five nuclear power plants have been corrected.

Los Alamos has also recently teamed with Sandia National Laboratories in Albuquerque to study the vulnerabilities of nuclear facilities to terrorist attacks, including the impact of an aircraft. (Nuclear facilities include nuclear power plants, plants that produce reactor fuel or medical isotopes, and the cooling ponds where spent nuclear fuel is stored.) The team is also developing ways to protect existing and future facilities from such attacks.

Over the last 30 years, Los Alamos has supplied most of the systems used by the International Atomic Energy Agency to track enriched, fresh, spent, or reprocessed reactor fuel at nuclear facilities worldwide. This work has reduced the possibility of nuclear materials being diverted from peaceful uses to make nuclear weapons.

Over the last 20 years, Los Alamos scientists have also used advanced statistical techniques and computer simulations to develop precise estimates of reactor safety under various operating conditions. A major result of this research is the Transient Reactor Analysis Code (TRAC), which simulates all aspects of nuclear power plant operation.

TRAC is currently the only code used by the NRC to obtain estimates of reactor safety under the most likely conditions (as opposed to worst-case estimates, which are ultraconservative). The Naval Reactors organization, which is responsible for the reactors used in U.S. submarines and other naval vessels, also uses TRAC to study reactor safety.

Recently, the NRC has used TRAC estimates to approve eighteen nuclear power plants to operate 20 years beyond their 40-year design life. The NRC has also used TRAC estimates to relax some power plant regulations without compromising plant safety, a measure that reduces plant complexity and cost. Finally, the NRC has used the estimates to authorize some plants to operate at power levels 5 to 10 percent above those specified in their original licenses, reducing the cost of the electricity the plants produce.

Another Los Alamos computer code widely used for reactor studies is MCNP, for Monte Carlo N-Particle (transport). MCNP simulates how neutrons and other forms of radiation move through a reactor's core. (Neutrons produce fission reactions in the reactor's uranium or plutonium fuel, which in turn produce more neutrons to generate a controlled chain reaction.) While TRAC simulates the operation of an entire nuclear power plant, MCNP focuses on the detailed physics in the reactor's core.

MCNP performs its calculations using Los Alamos data on nuclear cross sections, which measure the probabilities of a neutron interacting with the atoms of various elements. Such data are essential for detailed reactor-core calculations. The code and the cross-section data are used worldwide to design reactors, analyze radiation-shielding methods, calculate radiation doses for safety analysis, and design nuclear instruments and detectors.

Los Alamos scientists are also performing experiments to determine how the high levels of radiation in a reactor degrade its metallic structural members and its fuel rods, which consist of uranium or plutonium in ceramic forms. Materials scientist Robert Hanrahan is involved in this research. Understanding how intense radiation affects the materials in a reactor is key to determining reactor lifetime and safety, Hanrahan says.

One hundred and four nuclear power plants in thirty-one states provide 20 percent of the electricity used in the United States.

Some of these experiments are performed at the Los Alamos Neutron Science Center (LANSCE), where neutrons produced by a linear accelerator can be used to simulate the neutron flux in a nuclear reactor. In addition, a collaboration between researchers at the Laboratory and the University of Florida has developed ways to study corrosion in high-radiation environments, the major cause of the deterioration of the materials used in nuclear power systems.

Priming the Nuclear Pump

About a decade ago, Congress asked the NRC to improve the licensing process for nuclear power plants, which had often invited protracted lawsuits by environmental groups. These lawsuits, which could be filed even after the plant had been built and tested, could delay a plant's startup by several years or more. Such delays increased the plant's final cost and discouraged investors, the main reasons that reactors are not being built today.

The NRC's solution, which has been available since 1995, is to license a plant simply by confirming that its components correspond exactly with those in one of three approved plant designs: the Westinghouse AP-1000, the Combustion Engineering System 80+, and the General Electric ABWR. Working with scientists around the nation, the NRC used TRAC and small-scale experiments to determine that these designs are safe.

Codes like TRAC and MCNP will also be useful for designing new nuclear power plants that are simpler, safer, and cheaper than existing plants. The reason, Rao says, is that existing plants were scaled up from reactor designs developed in the 1950s to power submarines. As they were scaled up, the plants became more complicated and therefore more expensive and less reliable. In addition, each plant design was unique, which complicated licensing.

Commercial nuclear power plants could be much simpler and safer, Rao says, by generating the same amount of power in a larger volume of the reactor's core. In such an arrangement, the core could be cooled by natural convective flow of the cooling water rather than forced circulation. Convective cooling uses the fact that hot water naturally rises above cold water, whereas forced circulation uses pumps and valves to circulate the water. According to Rao, most postulated accidents involve either failed pumps or valves or breaks or leaks in the pipes that circulate the water.

Dealing with the Waste

To date, U.S. nuclear power plants have produced 40,000 tons of spent nuclear fuel. The spent fuel consists of 95.6 percent uranium, 3.0 percent stable or short-lived fission products, 0.9 percent plutonium, 0.3 percent cesium and strontium, 0.1 percent minor actinides (neptunium, americium, and curium), and 0.1 percent long-lived fission products in the form of isotopes of iodine and technetium.

The spent fuel's uranium is mostly uranium-238 and contains too little uranium-235 to be considered weapons grade. In fact, spent-fuel uranium is less radioactive than natural uranium ore and can, when separated from the spent fuel, be stored as "low-level" waste. The cesium and strontium, however, are literally quite hot from radioactive decay and require special storage for

Missouri Geographic Alliance

Steam rises from the cooling tower of a nuclear power plant in southern Callaway County, Missouri. The nuclear reactor is the dome-shaped building at right.

about 300 years, after which time they have mostly decayed into harmless elements. The plutonium isotopes and minor actinides remain dangerously radioactive for hundreds of thousands of years. Thus, about 1 percent of the spent fuel—the plutonium, the minor actinides, and the long-lived fission products—currently requires secure, long-term isolation.

The present plan is to store spent fuel rods at the Department of Energy's Yucca Mountain Facility in Nevada, a protected underground repository. But storing fuel rods from the one thousand 1-gigawatt nuclear power plants that could be deployed worldwide by 2050 would require a new repository the size of the Yucca Mountain Facility every three or four years.

Obviously, if there were less long-lived waste, fewer repositories would be needed. In collaboration with other national labs, universities, and industry, Los Alamos scientists are studying ways to separate the waste so that some of it can be recyled in reactors or transformed (transmuted) into short-lived or nonradioactive elements. If successful, this program, called the Advanced Fuel Cycle Initiative, could eliminate the need for a second national repository and reduce the number of global repositories required.

An element can be transmuted or fissioned (split by a nuclear reaction into lighter elements) by exposing it to neutrons. Copious neutrons are produced in reactors or by accelerators such as the one at LANSCE. Fissioning spent-fuel plutonium in a reactor would not only eliminate the need for its long-term storage but would also produce useful energy. Los Alamos has the only facility in the United States where reactor fuels that contain plutonium can be studied and developed.

The Hydrogen Bonus

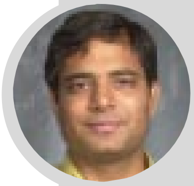
Nuclear reactors could help make a hydrogen economy feasible and further reduce emissions of greenhouse gases as well as our dependence on foreign oil. Burning gasoline in internal combustion engines produces carbon dioxide as well as nitrogen- and sulfur-based gas pollutants. Electric vehicles powered by hydrogen fuel cells produce only water vapor.

In fact, President Bush recently announced a national program to develop hydrogen-powered cars, trucks, homes, and businesses. At present, however, 90 percent of the hydrogen produced industrially is made by "reforming" natural gas. Although reformed hydrogen is economical, reforming produces large amounts of carbon dioxide. But if nuclear power plants could produce electricity more economically, they could produce hydrogen electrolytically by decomposing water into hydrogen and oxygen. Or special high-temperature reactors could thermally decompose water. No carbon dioxide would be produced by either option.

The Department of Energy's Nuclear Hydrogen Initiative calls for building a nuclear reactor to demonstrate the feasibility of generating hydrogen economically by 2015. Los Alamos simulation codes will likely be used to design such a reactor and to show that it is safe. ■

The Researchers

Robert Hanrahan Jr. has a B.S. and M.S. in nuclear engineering and a Ph.D. in materials science from the University of Florida. He joined the Lab as a technical staff member in 1996. His research has focused on materials behavior for nuclear weapon and reactor applications. He has been a technical reviewer for the materials corrosion and aging models used to evaluate the Yucca Mountain Facility.



D. V. Rao has a Ph.D. in nuclear engineering from the University of New Mexico. Since joining Los Alamos, he has directed several NRC-sponsored reactor studies and is currently the Lab's NRC program manager. His research interests include special-purpose nuclear reactors, energy security, nuclear counterproliferation, and risk assessment for homeland security.

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